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A Summary of the Water Quality Data Record for South Puget Sound 1934 to 1967

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SURVEILLANCE AND ANALYSIS

A SUMMARY OF THE WATER QUALITY DATA RECORD FOR SOUTH PUGET SOUND, 1934 TO 1967

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The report examines the physical and chemical oceanographic data recorded for South Puget Sound. The project on which it is based determines some statistical characteristics of the water quality data base by reducing it to monthly and annual mean values pf several parameters at selected sampling stations over certain sampling periods. These statistical analyses will be used for water quality modeling of the South Puget Sound eco-system, to determine future sampling needs, and to define monitoring strategies for assessing the impact of military, industrial, and metropolitan growth upon that system.

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A SUMMARY OF THE WATER QUALITY DATA RECORD

FOR SOUTH PUGET SOUND, 1934 TO 1967

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DEFINING THE PROJECT

Concern about pollution of the sub-region of Puget Sound south of Tacoma Narrows (Figure 1.) resulting from military, industrial and metropolitan development led to this investigation. Until recently, most investigators concentrated their studies on the Central Basin, paying little attention to South Puget Sound.

A large body of physical and chemical oceanographic data is recorded for the South Sound,[1] but the inventory contains little recent data. This project determines some statistical characteristics of the water quality data base by reducing it to monthly and annual mean values of several parameters at selected sampling stations over certain sampling periods. These statistical analyses will be used for water quality modeling of the South Puget Sound eco-system, to determine future sampling needs, and to define monitoring strategies for assessing the impact of military, industrial, and metropolitan growth upon that system.

[1] Collias, Eugene E. Index to Physical and Chemical Oceanographic Data of Puget Sound and its Approaches, 1932-1966, University of Washington, Department of Oceanography, Special Report No. 43, 1970, pp. 400-467.

THE DATA BASE

Origins

The State of Washington Department of Fisheries, and the University of Washington sampled intermittently in the South Sound from 1932 to 1967, without a comprehensive sampling plan. In 1970, Collias published an index of this data base, summarized by stations (defined as sampling occurring within a one-mile radius of the station location).[2] Parameters measured generally included temperature, salinity, dissolved oxygen gas (DO), dissolved inorganic phosphate, and sulfite waste liquor--nitrate or nitrite nitrogen, silicate-silicon, and alkalinity were less frequently measured.

Format

This data was acquired by the Environmental Protection Agency and stored in STORET, a large on-line data storage and retrieval system. The data is stored by sampling station and is retrievable by specifying the stations, the parameters, and the beginning and ending dates desired. The retrieval is both printed out and stored in a temporary data set by three major card groups--station heading cards (detailing information on geographic location, depth to sediments in feet below mean low low water, and standard station number of the sampling station), parameter cards (specifying names and dimensions of parameters), and data cards (recording the date, time of day and depth at which readings were taken, and the parameter readings).

[2] Ibid.

Restrictions

Although the retrieval system provides an option for computing means of the parameter values for specified time periods, stations, and high and low parameter values, no provision is made for taking into account the depth at which the readings were taken. The means generated, therefore, simply average equally weighted values of the parameters over the entire water column, implying equal depth-spacing of the readings. Since samples are generally taken closer together near the surface and at increasing intervals with greater depth, this method of computing means tends to assign greater weight to near-surface values--a bias particularly great in deeper stations.

Because the retrieval data set format is not suitable for performing calculations on the data, it is necessary to edit the retrieval before alternative modes of calculation can be employed.

REDUCTION OF THE DATA

Calculations

In order to overcome some of the limitations of the STORET retrieval system, a FORTRAN program was written to calculate monthly or annual depth-means of selected parameter values by station. The sampling time period, the stations, and the parameters are specified in the retrieval. The data cards are edited and read onto a temporary data set which is sorted--using a system utility routine--by station, year, month, and depth of reading and stored in a second temporary data set. The FORTRAN program reads this sorted data set to first average together the readings of a parameter taken at the same depth within a single month, then to calculate the depth-means by month and to print them in a table format or to write the them in a permanent data set for use in further calculations.

A depth-mean is a step-wise function which averages parameter readings that have been weighted by the associated change in depth between readings. Greater weight is given to readings taken at larger depth-intervals than to those taken at short intervals. The algorithm for this function is

$$CTOTL=(Z_1-Z_0+\frac{Z_2-Z_1}{2})C_1 + (\frac{Z_2-Z_1}{2}+\frac{Z_3-Z_2}{2})C_2 +\ldots$$

$$\ldots+ (\frac{Z_N-Z_{N-1}}{2}+Z_{N+1}-Z_N)C_N$$

and

$$CMEAN=CTOTL/Z_{N+1}$$

where Z_1 is the depth at which parameter concentration reading (C_1) was

taken, and where $Z_0=0$ and Z_{N+1} is the depth to the sediments. This algorithm generates a mean value of the parameter over the entire water-column, without the bias toward closely spaced readings, resulting from an arithmetic mean. (For ease of manipulation, an equivalent formulation

$$CTOTL=(Z_1-Z_0)(C_1) + (Z_2-Z_1)\left(\frac{C_1+C_2}{2}\right) +\ldots+ (Z_{N+1}-Z_N)(C_N)$$

was used for actual computer calculations.)

By the use of this algorithm, the change in depth between the surface and the first reading (Z_1-Z_0) is multiplied by the first parameter value (C_1). If a reading is taken at the surface, where $Z_0=0=Z_1$, the value Z_1-Z_0 equals zero and the product $C_1(Z_1-Z_0)$ also equals zero. But, if the first reading is taken a great distance below the surface where Z_1-Z_0 is large, it is possible to attribute a greater weight to the first reading of the parameter concentration. (The same situation holds for the weight of the last reading $(Z_{N+1}-Z_N)$, where the product $C_N(Z_{N+1}-Z_N)$ equals zero if the last reading is taken at the bottom and becomes large if taken at a great distance above the bottom.)

Assumptions and Conventions

Implicit assumptions in this method of computation and conventions adopted are discussed below.

Samples taken at a station on different days within a month are assumed to be taken at the same location (cf. Collias, where a one-mile radius defines each station[3]). No weight is given to the sampling

[3] Ibid., p. 5.

interval during a month, which is equivalent to assuming that a sample was taken at one time of a single day with multiple readings at some depths. Parameter values measured more than once at a given depth are averaged together to produce a single parameter value for that depth, regardless of the day of the month or the time of day of the multiple readings. Parameter values (C_j) thus obtained are assumed to be representative of that parameter for an associated depth range, defined generally by

$$\frac{Z_i - Z_{i-1}}{2} + \frac{Z_{i+1} - Z_i}{2}$$

(and by

$$Z_1 - Z_0 + \frac{Z_2 - Z_1}{2}$$

for the shallowest reading, and by

$$\frac{Z_N - Z_{N-1}}{2} + Z_{N+1} - Z_N$$

for the deepest reading of C_j).

Parameters for which no readings are recorded at a given depth are not used in the calculation of the average value for that depth nor in the calculation of the depth-mean for that month. Furthermore, if no readings are recorded for a given parameter throughout an entire month, the monthly mean of that parameter is assigned a value of zero and is not used in further calculations.

The sampling is assumed to have occurred from a surface located at mean low low water (MLLW). That is, a sampling depth of zero is assumed

to be at MLLW and the bottom is assumed to be at the station depth in feet below MLLW. The depth to sediments used in the computations (Z_{N+1}), however, is assumed to be the station depth, or the depth of the deepest reading, which ever is greater. A reading depth larger than the station depth could result from sampling in a different location than the standard station location (within a one-mile radius) or from a tidal height at some distance above MLLW. In either case, the "bottom" is established--for purposes of calculation--at the depth in feet of the deepest data record (rather than at the station depth).

Selection of Parameters, Stations, and Sampling Periods

Parameters for summary were selected on the basis of completeness of coverage, reflecting the classical selection of water quality parameters--water temperature measured by reversing thermometers, dissolved oxygen gas, salinity (an indicator of residence time and density), and dissolved inorganic phosphate (a nutrient).

Sampling stations and time periods were chosen initially by examination of the raw data and of Collias' Index.[4] The period from January, 1953, to December, 1954, shows good consecutive-month sampling at the generally deep stations east of Case Inlet in South Puget Sound; while from January 1957, to December, 1958, consecutive-month coverage is fair at the generally shallow stations in the waterways west and south of Case Inlet. Retrievals were run on an on-line facility for all known stations during these time periods, monthly means were calculated for each parameter by station, and the output was stored in a permanent

[4] Ibid.

data set for use in further calculations. The in-house WANG computer was used to transfer the permanent data set from the on-line facility to disk and to calculate the mean and standard deviation of each parameter over the two year period. Tables 1 and 2 were prepared from this output.

By examination of these tables, ten stations were selected which showed good contiguous data coverage and which were determined to be representative of each of the major inlets and passages in South Puget Sound. (Representativeness was based on location of the station approximately mid-way between the mouth and the head of the inlet or passage.) An eleventh station (407) was chosen for the length of its data record--nearly 100 months of sampling during the 1934 to 1967 period. Monthly and annual means were calculated for the entire data record of station 407 (Tables 3, 4A, and 4B), and monthly means were calculated for the two year periods at the ten representative stations (Tables 5 to 14). Plots were prepared from these tables (Figures 2 to 7).

OUTPUT

Figures

Figure 1 is a map showing the location of sampling stations in South Puget Sound (excluding those for which insufficient data was found). On this map, a small, dark triangle (▲) represents stations shown in plots (Figures 2 to 7), while a small, dark circle (●) denotes stations appearing in Tables 1 and 2. Figure 2 shows plots of monthly mean temperature and DO readings over the period from 1951 to 1967 at station 407 (prepared from Tables 4A and 4B), while Figures 3 to 7 are plots of monthly temperature and DO means at the ten representative stations over two year periods (from Tables 5 to 14).

The plots are keyed by quarter--an open triangle (△) represents winter (01 to 03); a solid circle (●), spring (04 to 06); a solid triangle (▲), summer (07 to 09); and an open circle (○) represents fall (10 to 12). This keying provides a basis for comparison between data points in different years or in plots at different stations or of unlike parameters. The vertical (i.e., temperature and DO) scales are identical in height and value on all keyed plots for further comparability of output.

Description of Output

The sampling stations shown in the plots (Figures 2 to 7) can generally be considered in two groups. The eastern stations (406, 407, and 419) are deep, with station depths ranging from 209 to 298 feet, while the western stations are generally shallow with depths ranging from 49

to 59 feet (with the exception of station 452 at 180 feet).

Plots of the deeper, eastern stations (Figures 2 and 3) show a distinctive, smooth annual temperature cycle with the mean ranging from 10.1 to 10.4°C and the standard deviation ranging from 1.6 to 1.7°C (from Table 1), for the period from 1953 to 1954. A somewhat less smooth annual DO cycle has mean values ranging from 7.5 to 7.7 mg/1 with the standard deviation ranging from 1.0 to 1.1 mg/1 for the same two year period. The temperature cycle is inversely related to the dissolved oxygen cycle at these deep stations. Plots of annual parameter means at station 407 (1951 to 1967) were prepared, but were not included in this report because the distribution of data points was biased due to erratic sampling intervals.

The shallow western stations (Figures 4 to 7) show a fairly smooth annual temperature cycle with mean values ranging from 11.2 to 13.4°C and standard deviations of 2.4 to 4.0°C, accompanied by a rather rough DO curve with mean values of 7.9 to 8.4 mg/1 and standard deviations of 1.0 to 1.5 mg/1 (from Table 2). A weakly inverse relationship exists between the temperature and dissolved oxygen in these shallow stations.

MONITORING STRATEGY

The statistical analyses presented in this report point to a need for strategic monitoring in South Puget Sound. The seasonal variations of depth-averaged water quality parameters (temperature and DO) in the deep stations are smaller and more predictable than in the shallower stations. Here the more stable status of the deeper waters mitigates the effects of short-term influences on the surface waters. Long-term monitoring of water quality trends could, therefore, be accomplished by monthly observations at a few representative deep stations, such as Devil's Head (407) or Nisqually Reach (406).

Within the shallow embayments such as Budd or Eld Inlet, however, seasonal variations are greater and more random in appearance, resulting from high-frequency sub-cycles (eg. the effects of diurnal light, temperature, and tidal cycles) which cannot be detected by the monthly sampling interval. High-frequency sampling will be required in these areas to determine the nature, as well as the extent, of variation in water quality.

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TABLE 1. SUMMARY OF WATER QUALITY DATA RECORD BY STATION
SOUTH PUGET SOUND, 1953 TO 1954

STATION NUMBER	NUMBER OF MONTHS	WATER TEMP. (CENT) AVE	WATER TEMP. (CENT) STD	D. O. (MG/L) AVE	D. O. (MG/L) STD	SALINITY (PPTH) AVE	SALINITY (PPTH) STD	PHOS (ORTHO) (MG/L P) AVE	PHOS (ORTHO) (MG/L P) STD
406	24	10.2	1.6	7.7	1.0	29.19	0.61	0.007	0.001
407	24	10.4	1.7	7.7	1.0	29.12	0.63	0.007	0.001
411	12	9.9	1.4	7.6	1.0	29.06	0.56	0.007	0.001
412	11	10.0	1.5	7.6	1.1	29.04	0.61	0.007	0.001
413	11	10.0	1.5	7.5	1.1	29.02	0.63	0.007	0.001
414	11	10.1	1.6	7.8	1.3	28.97	0.64	0.007	0.001
415	11	10.1	1.5	7.8	1.2	29.01	0.61	0.007	0.001
416	11	10.1	1.5	7.7	1.4	28.99	0.63	0.007	0.001
417	11	10.5	1.8	8.6	2.0	28.90	0.64	0.007	0.002
418	11	10.5	1.7	8.6	1.9	28.90	0.63	0.007	0.001
419	24	10.1	1.6	7.5	1.1	29.30	0.60	0.007	0.001
420	11	10.1	1.6	7.7	1.6	28.96	0.63	0.007	0.001
421	14	10.6	1.7	7.6	1.5	29.13	0.71	0.007	0.001
422	11	10.4	1.9	8.4	1.5	28.51	1.17	0.007	0.002
423	11	10.5	2.2	8.7	1.4	28.48	0.74	0.006	0.002
426	11	10.2	1.6	8.1	1.2	28.97	0.62	0.007	0.002
432	3	11.6	0.9	8.1	0.4	28.87	0.12	0.006	0.000
433	3	11.7	0.9	8.2	0.5	28.80	0.15	0.006	0.001
434	3	13.5	0.9	8.4	1.9	28.37	0.20	0.005	0.002
436	3	12.3	0.9	8.1	0.7	28.65	0.16	0.006	0.001

TABLE 2. SUMMARY OF WATER QUALITY DATA RECORD BY STATION
SOUTH PUGET SOUND, 1957 TO 1958

STATION NUMBER	NUMBER OF MONTHS	WATER TEMP. (CENT) AVE	WATER TEMP. (CENT) STD	D.O. (MG/L) AVE	D.O. (MG/L) STD	SALINITY (PPTH) AVE	SALINITY (PPTH) STD	PHOS (ORTHO) (MG/L P) AVE	PHOS (ORTHO) (MG/L P) STD
405	6	10.7	1.7	7.1	0.7	29.59	0.48	0.007	0.002
406	9	9.9	2.1	7.7	1.0	29.25	0.52	0.007	0.002
407	10	10.1	2.1	7.4	1.5	29.28	0.53	0.007	0.002
411	7	10.2	2.0	7.4	1.0	29.53	0.54	0.007	0.002
413	9	9.8	2.0	7.7	1.0	29.39	0.49	0.007	0.002
416	7	10.3	2.0	7.4	1.0	29.46	0.54	0.007	0.002
419	9	9.8	2.0	7.7	1.1	29.36	0.50	0.007	0.002
421	9	9.9	2.0	8.0	1.2	29.26	0.52	0.008	0.002
423	7	11.0	2.3	8.5	1.2	29.02	0.59	0.007	0.002
431	17	11.0	2.3	7.6	1.1	29.22	0.46	0.007	0.001
432	2	8.1	1.0	9.0	1.3	28.86	0.08	0.000	0.000
433	18	11.1	2.4	7.7	1.2	29.07	0.46	0.007	0.002
434	18	11.6	3.1	8.2	1.3	28.59	0.55	0.007	0.002
436	8	10.1	2.1	8.3	1.3	28.65	0.37	0.008	0.002
437	12	13.9	4.1	8.6	1.4	27.70	1.37	0.006	0.002
438	17	11.1	2.7	8.0	1.1	28.81	0.53	0.007	0.002
441	9	13.0	2.4	7.9	1.0	29.05	0.53	0.006	0.001
442	2	11.9	4.2	8.1	0.6	28.79	0.42	0.007	0.001
450	8	10.5	2.3	8.5	1.0	28.77	0.27	0.006	0.002
451	2	13.3	1.6	7.1	2.3	29.68	0.26	0.008	0.001
452	18	11.2	2.6	7.9	1.1	28.90	0.49	0.007	0.001
453	19	11.9	3.0	8.3	1.4	28.77	0.62	0.007	0.002
455	[illegible]	12.5	3.4	8.8	0.7	28.48	0.47	0.007	0.001
456	20	12.3	3.5	8.4	1.4	28.01	1.02	0.007	0.002
458	12	12.4	3.4	7.8	1.3	28.29	0.98	0.007	0.001
459	7	10.3	2.5	8.2	1.3	28.44	0.38	0.007	0.002
461	19	11.9	2.8	8.2	1.5	28.67	0.59	0.007	0.001
462	5	9.1	2.0	8.6	2.7	28.05	0.41	0.009	0.001
463	13	13.2	2.7	6.7	2.3	28.26	0.79	0.008	0.001
465	20	11.7	2.8	8.3	1.5	28.78	0.60	0.007	0.001
466	19	12.0	3.1	8.2	1.3	28.60	0.66	0.007	0.001
467	15	12.7	3.1	7.6	1.5	28.59	0.75	0.008	0.001
472	20	12.2	3.4	8.5	1.5	28.26	0.88	0.007	0.002
474	20	12.6	3.9	8.3	1.3	27.98	0.98	0.007	0.002
475	17	13.0	4.4	8.1	1.8	27.89	1.08	0.008	0.001
476	13	13.7	3.9	8.2	1.5	27.23	2.70	0.007	0.001
480	7	12.1	3.3	7.7	1.4	27.15	2.59	0.007	0.001
482	15	13.4	4.0	8.1	1.2	26.74	2.50	0.007	0.001
485	15	13.6	4.4	7.9	1.1	26.46	2.33	0.007	0.001
488	15	14.2	4.9	7.4	1.2	25.20	3.03	0.007	0.001
490	7	15.8	4.4	7.6	1.2	24.79	2.51	0.007	0.001

TABLE 3. SUMMARY OF WATER QUALITY DATA RECORD BY YEAR

SOUTH PUGET SOUND, STATION 407

YEAR	WATER TEMP. CENT.	ANNUAL DEPTH-AVERAGE DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
34	11.6	7.2	28.85	0.005
35	11.6	8.2	29.25	0.004
36	9.6	8.2	29.26	0.008
37	7.4	6.7	29.42	0.010
38	12.6	8.5	29.15	0.005
40	11.2	7.8	29.14	0.005
41	14.3	8.3	29.88	0.004
51	7.4	8.7	27.66	0.0
52	10.2	6.9	29.77	0.0
53	10.6	7.6	29.52	0.007
54	9.6	8.1	28.60	0.007
55	8.6	8.4	28.94	0.007
56	6.3	8.8	28.04	0.008
57	9.4	7.7	29.22	0.007
58	11.1	6.8	29.39	0.008
59	10.2	7.6	28.85	0.008
60	8.7	7.9	28.84	0.008
61	9.9	7.8	28.81	0.007
62	7.2	8.6	29.13	0.009
63	12.0	6.6	29.91	0.007
64	9.4	7.8	29.56	0.007
65	10.3	7.7	29.24	0.007
66	9.8	.7	29.07	0.006
67	9.0	9.2	28.96	0.006

TABLE 44. SUMMARY OF WATER QUALITY DATA RECORD BY MONTH

SOUTH PUGET SOUND, STATION 407

YEAR.MONTH	WATER TEMP. CENT	MONTHLY DEPTH-AVERAGE DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
34.04	9.6	8.6	28.27	0.005
34.07	13.0	6.3	29.23	0.004
35.07	11.6	8.2	29.25	0.004
36.01	8.3	8.2	29.51	0.008
36.06	11.0	8.2	28.97	0.0
37.04	7.4	6.7	29.47	0.010
38.07	12.6	8.5	29.15	0.005
40.02	8.9	7.9	29.12	0.007
40.07	13.2	7.8	29.16	0.003
41.08	14.3	8.3	29.88	0.004
51.03	7.4	8.7	27.66	0.0
52.04	8.2	6.2	29.06	0.0
52.05	10.1	8.9	29.25	0.0
52.10	12.6	6.6	30.14	0.0
52.11	11.5	6.0	30.33	0.0
52.12	9.4	6.9	30.29	0.0
53.01	8.6	7.7	29.88	0.0
53.02	8.3	8.5	28.79	0.0
53.03	8.2	8.5	28.70	0.0
53.04	8.6	8.7	29.02	0.0
53.05	9.7	9.3	29.16	0.0
53.06	10.9	7.8	29.18	0.0
53.07	12.5	7.2	29.29	0.007
53.08	13.0	6.6	29.52	0.006
53.09	13.1	7.0	30.02	0.007
53.10	12.1	6.7	29.97	0.007
53.11	11.3	6.2	29.83	0.008
53.12	10.3	7.5	29.82	0.009
54.01	9.2	7.9	28.50	0.008
54.02	8.1	8.5	28.05	0.007
54.03	7.9	8.8	27.90	0.007
54.04	8.6	8.7	28.13	0.007
54.05	9.2	9.5	28.34	0.006
54.06	10.7	8.2	28.85	0.006
54.07	11.4	8.0	28.85	0.005
54.08	12.6	7.9	29.00	0.006
54.09	12.2	6.3	29.54	0.008
54.10	11.6	6.3	29.67	0.007
54.11	10.9	6.5	29.61	0.008
54.12	9.7	7.2	29.23	0.008
55.01	8.7	7.9	28.98	0.008
55.02	8.0	8.0	28.66	0.008
55.03	7.3	9.1	28.69	0.008
55.05	8.6	10.4	28.86	0.005
55.11	10.6	6.5	29.50	0.008
56.01	7.1	8.5	28.19	0.009
56.02	6.3	8.8	28.03	0.008
57.01	7.4	8.0	28.85	0.008
57.04	7.6	8.9	28.72	0.007

TABLE 4 B. SUMMARY OF WATER QUALITY DATA RECORD BY MONTH

SOUTH PUGET SOUND, STATION 407

YEAR.MONTH	WATER TEMP. CENT	MONTHLY DEPTH-AVERAGE DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
57.05	8.7	9.6	28.75	0.0
57.06	10.6	8.5	28.87	0.004
57.11	12.0	4.6	30.02	0.009
57.12	10.3	6.8	30.01	0.007
58.02	8.7	7.1	29.03	0.008
58.09	14.4	6.1	29.75	0.007
58.11	11.2	6.8	29.72	0.0
58.12	10.1	7.1	29.05	0.009
59.03	8.2	8.5	28.22	0.007
59.06	10.7	8.4	28.61	0.006
59.10	12.1	6.5	29.58	0.008
59.12	9.7	7.0	28.97	0.009
60.01	7.9	7.8	28.66	0.008
60.05	8.8	8.8	28.59	0.007
60.12	9.4	7.3	29.23	0.009
61.04	9.0	8.7	27.86	0.007
61.11	10.9	6.7	29.93	0.009
62.03	7.2	8.6	29.13	0.009
63.09	13.3	6.5	29.90	0.007
63.10	12.8	6.2	30.10	0.007
63.11	11.4	6.8	29.90	0.007
63.12	10.2	7.2	29.36	0.008
64.01	9.4	7.7	28.89	0.008
64.02	8.5	8.5	28.25	0.008
64.03	8.1	8.9	28.29	0.007
64.04	8.6	9.2	28.61	0.006
64.05	8.8	8.2	29.49	0.006
64.06	10.7	8.2	29.07	0.006
64.07	11.9	7.4	29.22	0.006
64.08	12.6	7.0	29.37	0.007
64.09	12.6	6.8	29.54	0.007
64.10	12.2	6.6	29.68	0.007
64.11	11.0	6.4	29.78	0.007
64.12	9.2	6.8	29.44	0.008
65.01	7.6	7.9	28.88	0.009
65.02	7.4	8.1	28.33	0.008
65.03	7.7	8.3	28.27	0.008
65.04	8.0	8.6	28.55	0.007
65.05	9.1	8.5	28.95	0.006
65.06	10.8	8.1	29.14	0.006
65.07	12.5	7.7	29.42	0.006
65.08	13.2	7.4	29.67	0.006
65.09	13.1	6.9	29.99	0.007
65.10	12.4	6.3	30.15	0.008
65.11	11.5	6.4	30.13	0.008
65.12	10.2	7.0	29.96	0.009
66.05	9.8	8.7	29.07	0.006
67.05	9.0	9.2	28.96	0.006

TABLE 5. SUMMARY OF WATER QUALITY DATA RECORD BY MONTH

SOUTH PUGET SOUND, STATION 406

YEAR.MONTH	WATER TEMP. CENT	MONTHLY DEPTH-AVERAGE DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
53.01	8.7	7.8	29.98	0.0
53.02	8.3	8.8	29.03	0.0
53.03	8.2	8.5	28.93	0.0
53.04	8.3	8.3	29.21	0.0
53.05	9.3	8.9	29.40	0.0
53.06	11.0	8.0	29.12	0.0
53.07	12.2	7.2	29.13	0.006
53.08	12.7	6.5	29.57	0.007
53.09	12.6	6.5	30.07	0.007
53.10	12.0	6.7	29.85	0.007
53.11	11.2	6.1	29.88	0.008
53.12	10.3	7.2	29.80	0.008
54.01	9.2	8.0	28.48	0.008
54.02	8.1	8.5	28.20	0.007
54.03	7.8	8.8	28.12	0.007
54.04	8.4	8.8	28.31	0.007
54.05	9.0	9.4	28.06	0.005
54.06	10.2	8.0	28.97	0.006
54.07	11.0	7.7	28.95	0.006
54.08	12.3	7.8	29.04	0.0
54.09	12.1	6.4	29.54	0.008
54.10	11.6	6.5	29.64	0.007
54.11	10.7	6.3	29.82	0.008
54.12	9.8	7.1	29.39	0.008

TABLE 6. SUMMARY OF WATER QUALITY DATA RECORD BY MONTH

SOUTH PUGET SOUND, STATION 419

YEAR.MONTH	WATER TEMP. CENT	MONTHLY DEPTH-AVERAGE DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
53.01	8.6	7.8	30.02	0.0
53.02	8.3	8.6	29.04	0.0
53.03	8.2	8.3	28.98	0.0
53.04	8.3	8.1	29.24	0.0
53.05	9.2	8.5	29.30	0.0
53.06	10.7	7.9	29.26	0.0
53.07	11.9	6.4	29.37	0.007
53.08	11.9	6.7	29.92	0.006
53.09	12.6	0.0	30.03	0.007
53.10	12.0	5.9	30.15	0.008
53.11	11.4	6.0	30.09	0.008
53.12	10.4	7.0	29.97	0.008
54.01	9.3	8.0	28.85	0.008
54.02	8.0	8.6	28.35	0.008
54.03	7.9	8.8	28.12	0.0
54.04	8.4	8.7	28.31	0.007
54.05	9.0	9.6	28.55	0.006
54.06	10.2	7.9	28.97	0.007
54.07	11.1	8.0	28.94	0.006
54.08	11.9	7.2	29.10	0.006
54.09	11.8	5.8	29.66	0.008
54.10	11.5	5.8	29.79	0.008
54.11	10.9	6.1	29.85	0.008
54.12	9.8	7.0	29.43	0.007

TABLE 7. SUMMARY OF WATER QUALITY DATA RECORD BY MONTH

SOUTH PUGET SOUND, STATION 434

YEAR.MONTH	WATER TEMP. CENT	MONTHLY DEPTH-AVERAGE DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
57.01	6.7	8.3	28.46	0.009
57.05	11.2	10.9	28.07	0.0
57.06	12.2	8.1	28.41	0.004
57.08	14.1	10.0	29.04	0.009
57.11	11.5	5.7	29.77	0.009
57.12	8.1	9.0	28.34	0.008
58.01	8.3	8.0	28.26	0.0
58.02	8.6	6.8	28.24	0.009
58.03	8.5	8.8	27.67	0.007
58.04	9.7	9.0	28.01	0.005
58.05	12.1	10.0	28.24	0.006
58.06	13.3	8.7	28.33	0.008
58.07	17.2	7.9	28.68	0.006
58.08	16.4	7.0	28.86	0.008
58.09	16.1	6.3	29.33	0.008
58.10	14.4	8.3	29.47	0.005
58.11	10.8	7.9	28.94	0.0
58.12	9.9	7.4	28.49	0.009

TABLE 8. SUMMARY OF WATER QUALITY DATA RECORD BY MONTH

SOUTH PUGET SOUND, STATION 441

YEAR.MONTH	WATER TEMP. CENT	MONTHLY DEPTH-AVERAGE DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
57.08	13.4	7.5	29.48	0.006
57.12	9.1	7.2	29.24	0.008
58.04	9.5	8.4	28.22	0.006
58.05	12.1	10.2	28.40	0.006
58.06	13.2	8.4	28.61	0.005
58.07	15.0	8.1	29.01	0.006
58.08	15.6	7.7	29.29	0.006
58.09	15.6	6.7	29.49	0.007
58.10	13.9	7.0	29.73	0.007

TABLE 9. SUMMARY OF WATER QUALITY DATA RECORD BY MONTH

SOUTH PUGET SOUND, STATION 452

YEAR.MONTH	MONTHLY DEPTH-AVERAGE WATER TEMP. CENT	DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
57.01	7.2	8.2	28.69	0.008
57.05	9.6	10.9	28.44	0.0
57.06	11.7	8.8	28.64	0.004
57.08	13.6	7.9	29.21	0.007
57.11	10.7	5.7	29.76	0.008
57.12	9.0	7.6	28.79	0.008
58.01	8.6	7.6	28.91	0.0
58.02	8.6	7.1	28.51	0.008
58.03	8.5	8.1	28.25	0.007
58.04	9.3	8.6	28.18	0.006
58.05	11.6	9.6	28.49	0.005
58.06	12.9	8.3	28.67	0.005
58.07	14.7	7.8	29.01	0.006
58.08	15.3	7.6	29.33	0.007
58.09	15.4	7.5	29.54	0.006
58.10	13.9	7.1	29.73	0.006
58.11	11.1	7.0	29.35	0.0
58.12	10.0	7.2	28.73	0.009

TABLE 10. SUMMARY OF WATER QUALITY DATA RECORD BY MONTH

SOUTH PUGET SOUND, STATION 456

YEAR.MONTH	WATER TEMP. CENT	MONTHLY DEPTH-AVERAGE DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
57.01	5.9	8.8	27.54	0.008
57.05	11.9	12.3	27.56	0.0
57.06	13.1	8.3	28.30	0.004
57.08	15.6	8.5	28.83	0.006
57.09	15.9	9.0	29.12	0.006
57.10	13.6	5.5	29.41	0.008
57.11	11.2	6.2	29.10	0.009
57.12	8.2	7.7	27.14	0.008
58.01	8.3	8.4	26.03	0.007
58.02	8.5	7.8	27.23	0.008
58.03	8.3	8.5	26.70	0.006
58.04	10.1	8.8	26.84	0.006
58.05	14.5	10.7	27.67	0.004
58.06	15.2	8.7	28.09	0.005
58.07	17.4	9.7	28.54	0.006
58.08	17.4	8.5	29.05	0.006
58.09	17.0	8.5	29.17	0.006
58.10	14.3	7.6	29.34	0.007
58.11	10.4	7.8	27.08	0.0
58.12	9.6	7.4	27.38	0.009

TABLE 11. SUMMARY OF WATER QUALITY DATA RECORD BY MONTH

SOUTH PUGET SOUND, STATION 461

YEAR.MONTH	WATER TEMP. CENT	MONTHLY DEPTH-AVERAGE DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
57.01	6.7	8.4	28.19	0.008
57.05	10.2	12.1	28.11	0.0
57.06	11.9	8.8	28.58	0.006
57.08	14.5	9.5	28.95	0.007
57.09	14.7	8.4	29.32	0.007
57.10	13.4	6.2	29.50	0.008
57.11	11.3	5.3	29.50	0.009
58.01	8.5	7.8	28.32	0.0
58.02	8.6	7.1	28.20	0.008
58.03	8.4	7.8	27.74	0.007
58.04	9.5	8.6	27.96	0.006
58.05	12.3	10.3	28.24	0.005
58.06	13.6	9.0	28.44	0.005
58.07	15.2	0.0	28.81	0.006
58.08	16.1	8.6	29.15	0.007
58.09	15.8	8.2	29.35	0.007
58.10	13.9	7.3	29.65	0.007
58.11	10.9	7.4	28.53	0.0
58.12	9.9	7.2	28.19	0.009

TABLE 12. SUMMARY OF WATER QUALITY DATA RECORD BY MONTH

SOUTH PUGET SOUND, STATION 466

YEAR.MONTH	MONTHLY DEPTH-AVERAGE WATER TEMP. CENT	DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
57.01	6.1	8.6	27.90	0.008
57.05	10.5	11.2	28.12	0.0
57.06	12.7	8.8	28.47	0.004
57.08	14.7	8.2	29.06	0.007
57.09	15.0	8.2	29.34	0.007
57.10	13.6	7.0	29.63	0.008
57.11	11.0	6.2	29.39	0.009
57.12	9.3	6.6	28.33	0.008
58.01	8.4	8.0	28.12	0.008
58.02	8.6	8.0	27.67	0.008
58.03	8.4	8.3	27.68	0.008
58.04	9.8	8.4	27.76	0.007
58.05	13.1	10.5	28.17	0.005
58.06	14.4	9.6	28.41	0.006
58.07	15.3	0.0	28.75	0.006
58.08	16.3	8.5	29.12	0.008
58.09	16.3	6.8	29.39	0.008
58.10	14.2	7.4	29.53	0.007
58.11	10.8	7.1	28.65	0.0

TABLE 13. SUMMARY OF WATER QUALITY DATA RECORD BY MONTH

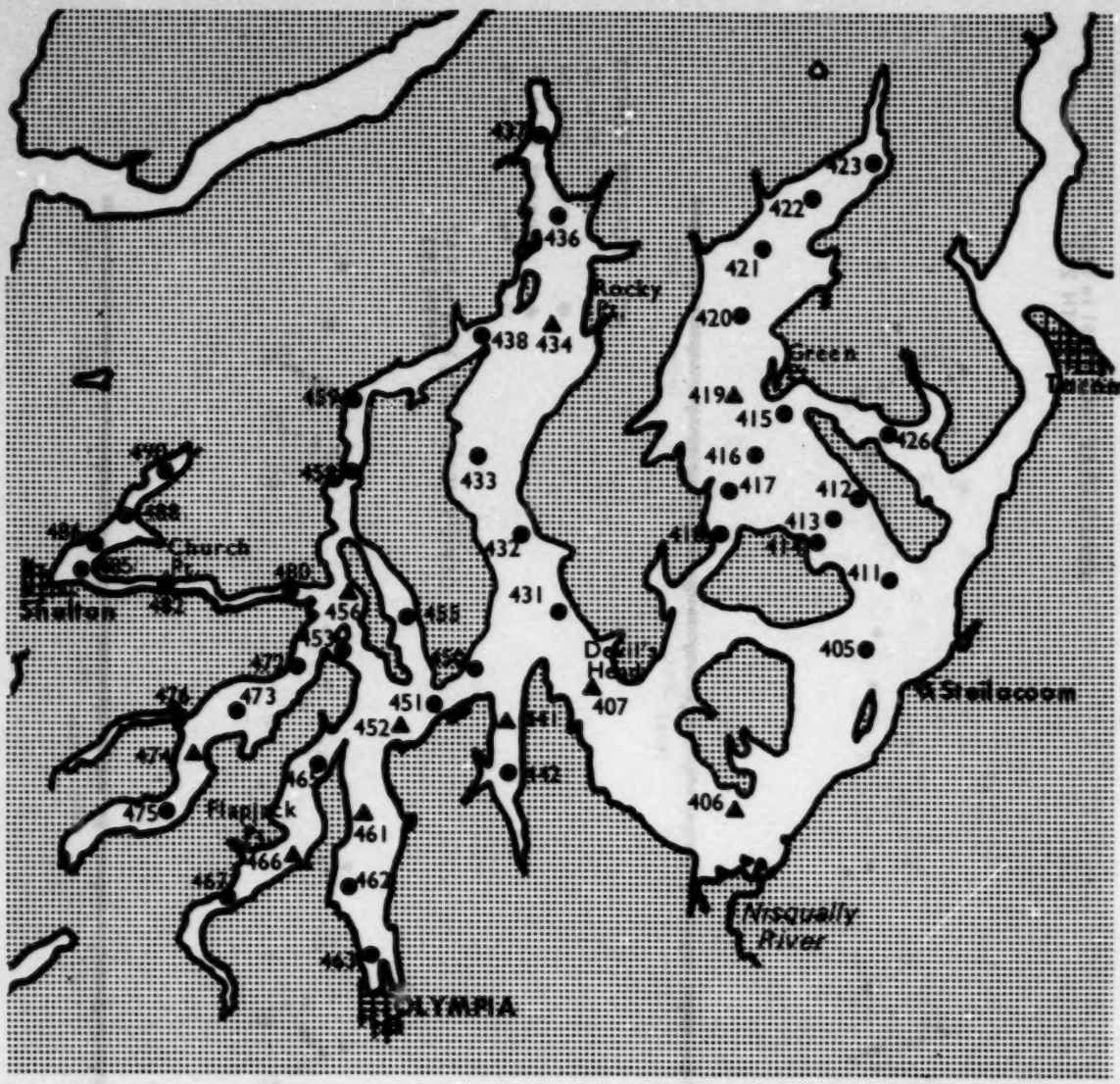
SOUTH PUGET SOUND. STATION 474

YEAR.MONTH	WATER TEMP. CENT	MONTHLY DEPTH-AVERAGE DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
57.01	5.3	9.0	26.97	0.009
57.05	12.1	11.4	27.58	0.0
57.06	14.6	8.8	28.14	0.003
57.08	16.3	8.8	28.81	0.007
57.09	16.5	8.5	29.12	0.007
57.10	14.1	7.2	29.30	0.007
57.11	10.8	5.5	28.88	0.009
57.12	8.4	7.9	27.52	0.008
58.01	8.2	8.2	26.95	0.007
58.02	8.6	8.0	26.70	0.008
58.03	8.4	8.5	26.43	0.007
58.04	10.0	8.3	26.88	0.006
58.05	15.1	10.4	27.69	0.005
58.06	15.9	9.8	28.10	0.005
58.07	17.9	6.8	28.65	0.007
58.08	18.8	8.0	29.02	0.009
58.09	17.2	8.2	29.26	0.007
58.10	14.5	7.4	29.22	0.007
58.11	10.3	7.5	27.15	0.0
58.12	9.5	7.4	27.18	0.009

TABLE 14. SUMMARY OF WATER QUALITY DATA RECORD BY MONTH

SOUTH PUGET SOUND, STATION 482

YEAR.MONTH	WATER TEMP. CENT	MONTHLY DEPTH-AVERAGE DO MG/L	SALINITY PPTH	PHOS-DIS ORTHO MG/L P
57.08	16.7	7.3	28.26	0.007
57.09	16.3	9.1	29.01	0.006
57.10	13.8	6.2	29.27	0.007
57.11	10.9	5.3	27.98	0.010
57.12	7.7	8.5	23.78	0.008
58.01	7.9	8.3	22.95	0.007
58.02	8.4	8.3	23.77	0.007
58.03	8.3	8.6	23.35	0.007
58.04	10.9	8.4	23.49	0.006
58.05	16.4	9.8	26.34	0.004
58.06	15.4	8.6	28.03	0.006
58.07	18.2	9.2	28.15	0.006
58.08	18.9	7.7	28.58	0.007
58.09	17.3	8.7	29.02	0.006
58.10	14.4	7.5	29.16	0.007



LEGEND: ▲ Indicates Stations Shown in Plots, Fig. 2 to 7

FIGURE 1. STATIONS IN SOUTH PUGET SOUND (After Collias)

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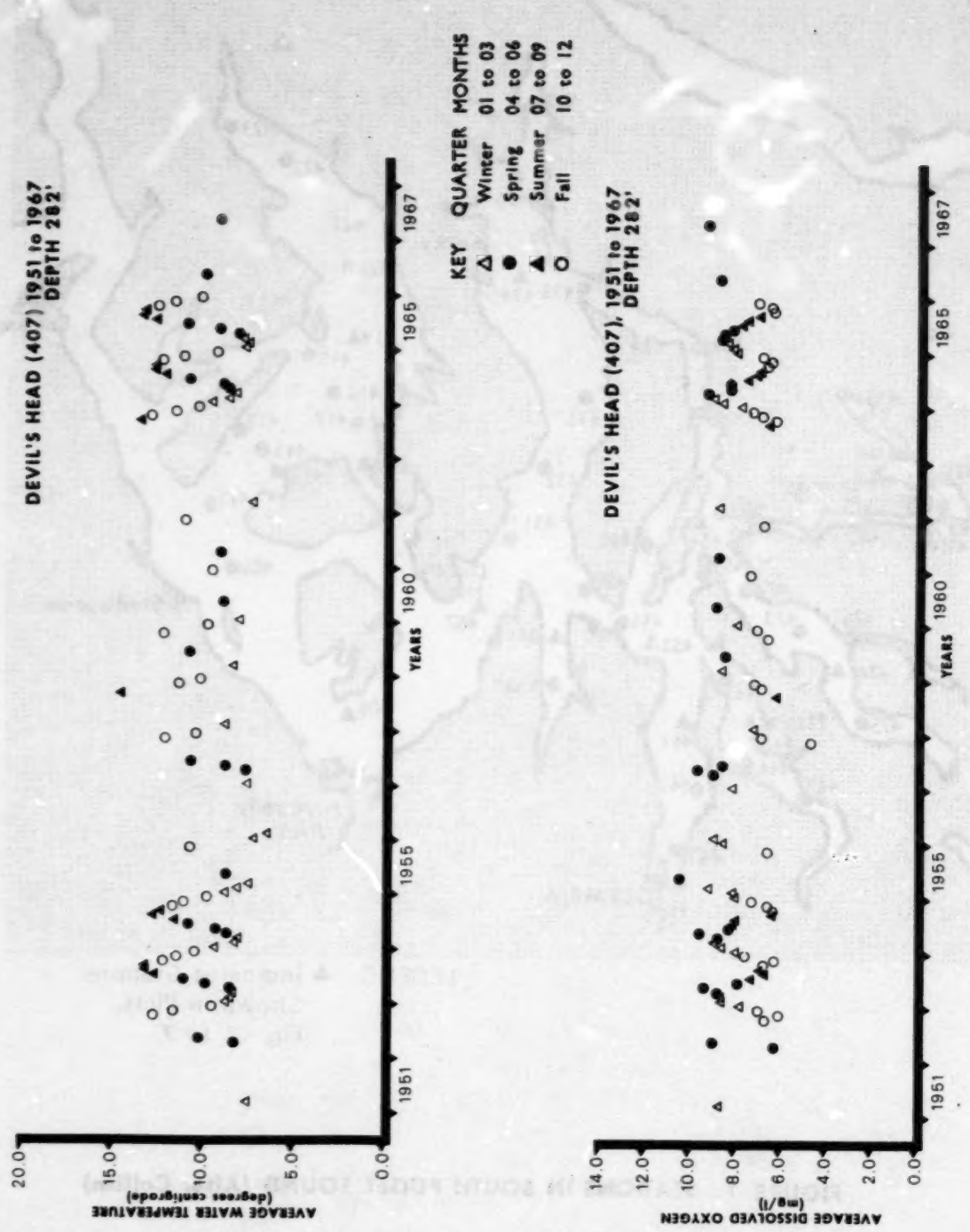

Figure 2. Average Monthly Water Temperature and Dissolved Oxygen
South Puget Sound, Devil's Head

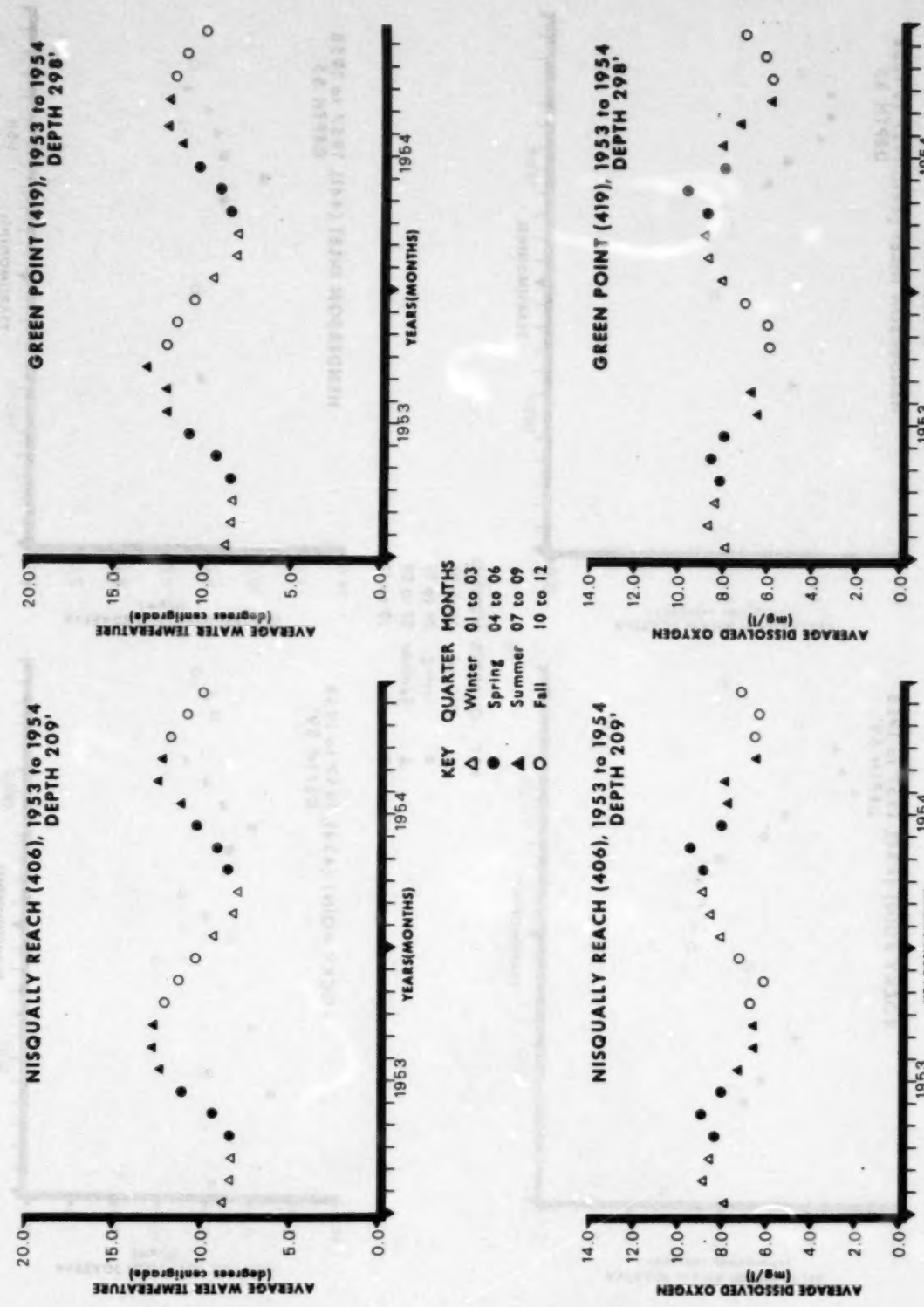

Figure 3. Average Monthly Water Temperature and Dissolved Oxygen South Puget Sound, Nisqually Reach and Green Point

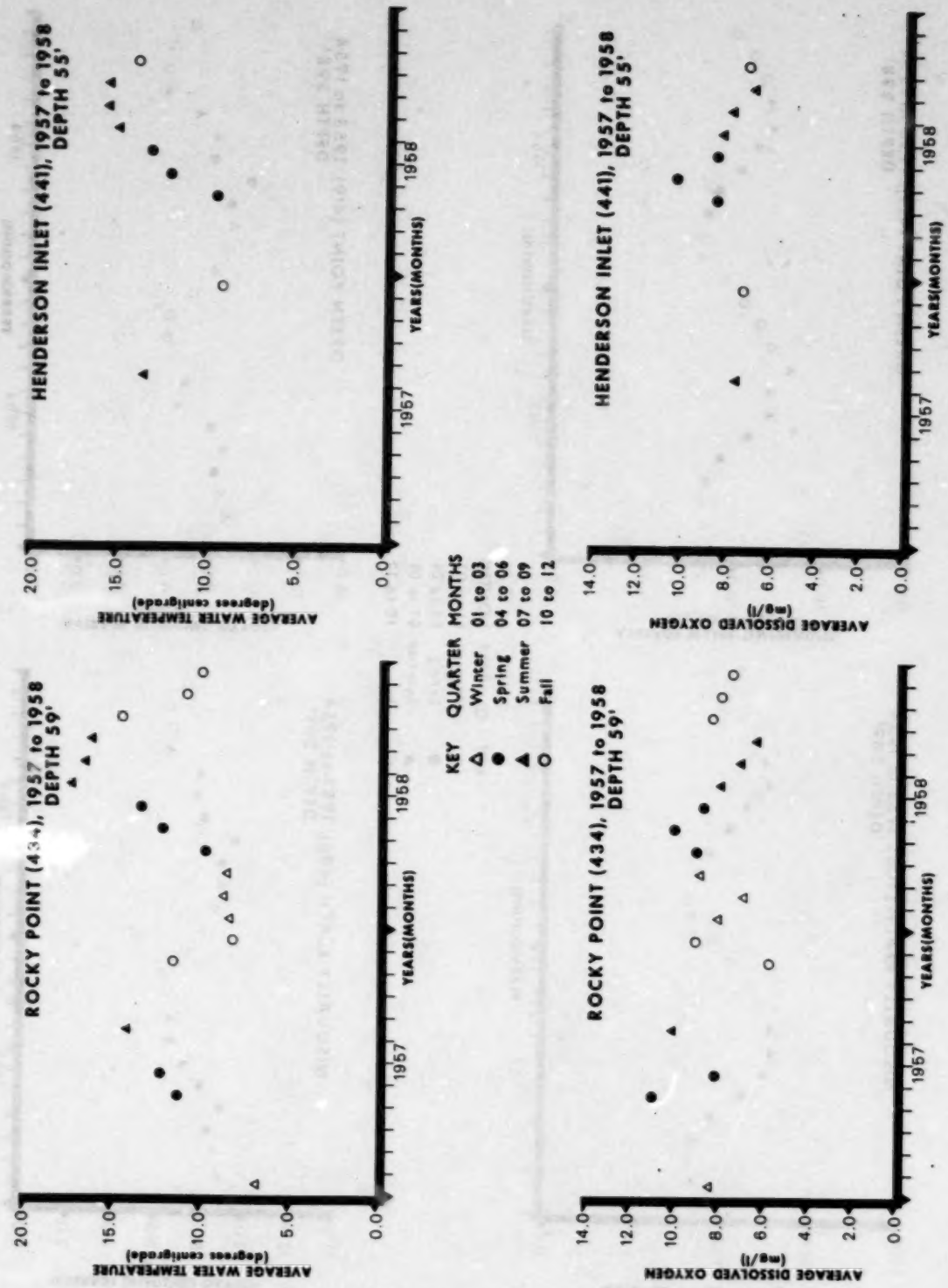

Figure 4. Average Monthly Water Temperature and Dissolved Oxygen South Puget Sound, Rocky Point and Henderson Inlet

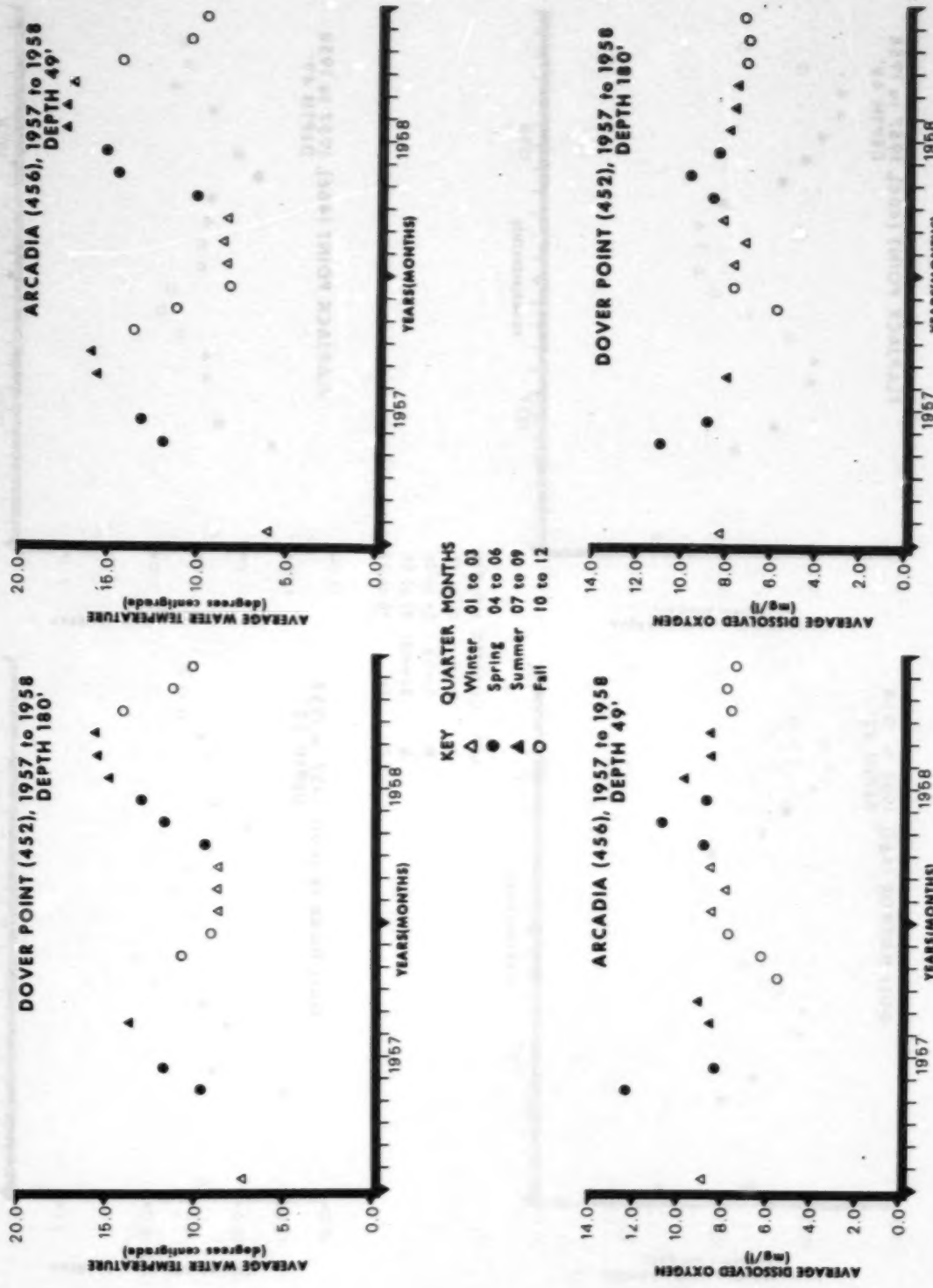

Figure 5. Average Monthly Water Temperature and Dissolved Oxygen South Puget Sound, Dover Point and Arcadia

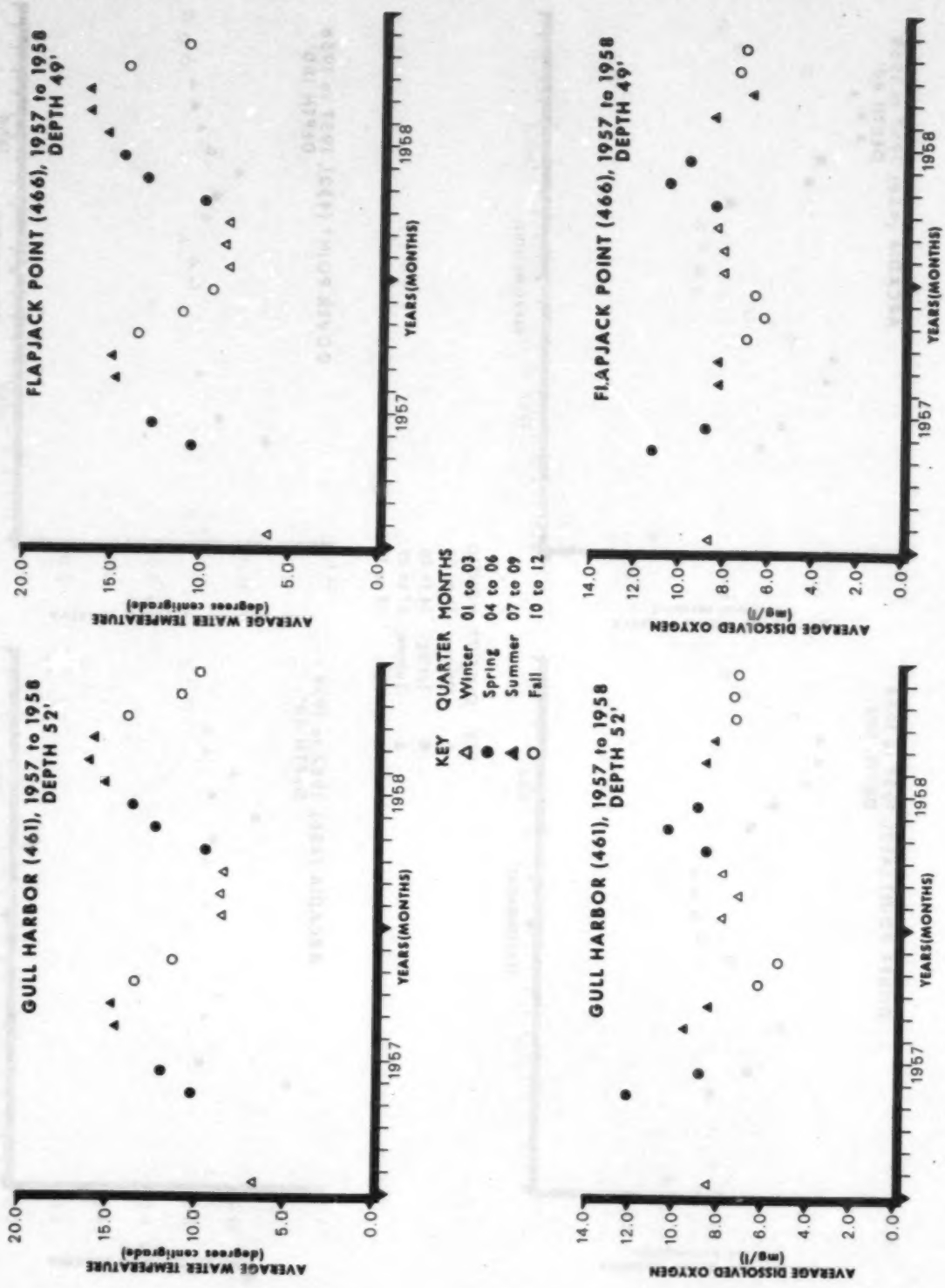

Figure 6. Average Monthly Water Temperature and Dissolved Oxygen South Puget Sound, Gull Harbor and Flapjack Point

Figure 7. Average Monthly Water Temperature and Dissolved Oxygen South Puget Sound, New Kamilche and Church Point